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RESIDUAL GAS INVESTIGATIONS DURING THE ESRO I SATELLITE TESTS

George Sänger and Walter Shickle[1]

ABSTRACT. The two flight units of ESRO-1, named Aurorae and Boreas in orbit, were tested at ESTEC in the space simulation chambers HBF 2 and HBF 3. During these tests, residual-gas measurements were made with the aid of a Veeco GA4 mass spectrometer. The outgassing rate of the spacecraft and the composition of the residual gas were studied as functions of test duration satellite attitude with respect to solar radiation. If the initial and final stages of such tests are ignored, the results show that the quantity of hydrocarbon gas derived from the spacecraft is of the same order of magnitude as that derived from the oil used in the space-simulation chamber.

/1*

Index of the Symbols and Abbreviations used:

α	Probability of adhesion
F	Area of the cryogenic pump (cm^2)
H	Heat of evaporation (cal/Mol)
M	Molecular weight
P	Partial pressure (Torr)
p	Vapor pressure (Torr)
Q	Gas amount pumped away (Torr-l)
Q'	Gas amount pumped away unit of time (Torr-l)
R	Universal gas constant (cal/deg·Mol)

*Numbers in the margin indicate pagination in the original foreign text.

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S	Suction capacity of the pump (l/sec)
T	Temperature °K
t	Time (sec)

1. GENERAL OBSERVATIONS

Satellite producers are concerned about precipitants from residual gas in the space simulation chamber on satellites during investigations of heat equilibrium. These precipitants could modify the surface properties or damage the experiment as a consequence. For that reason, the space chamber is especially critical. As far as degasification of the satellite is concerned, we are generally satisfied when colors with "small" outgassing and "space-qualified" components are used. On the other hand, a satellite cannot usually be pretreated in a manner which would be desirable in vacuum technology (for example, burnout). One is therefore forced to provide as clean a residual gas in a space chamber as is possible.

In the ESTEC, there are two space simulation chambers in operation — a smaller one, designated HBF 2, test volume of about 1.8 m Ø, and a larger one, called HBF 3, test volume of about 2.5 m Ø. They are both equipped with oil diffusion pumps [1]. Because no additional openings are provided in the cold wall during the heat equilibrium test, it is not possible at this time to insert the mass spectrometer tubes within the cold wall, despite the fact that this would be desirable for exact measurements. For that reason, a tube was set up in order to lessen the pumping effectiveness of the cold wall on the condensable components. This reduces the conductivity and can not prevent any absorption in the tube (see Figure 1). These first measurements in the ESTEC are not satisfactory for that reason to varying degrees and should be decidedly improved for the forthcoming prototype tests of the TD satellite, which is especially sensitive due to its optical experiments. Corresponding flanges and cold wall penetrations are provided in the HBF 3 model.

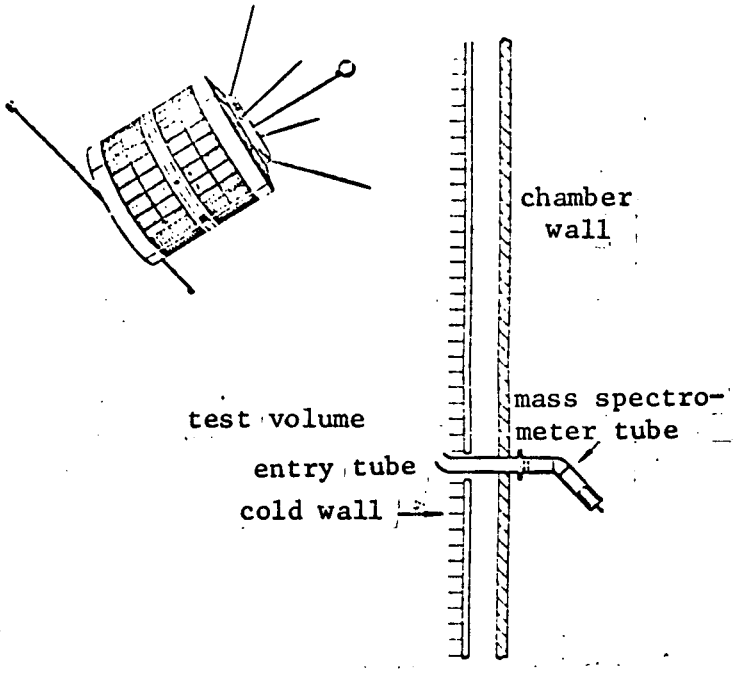

Figure 1. Arrangement of the mass spectrometer tube schematically.

In this work, only the most important results will be discussed. The reader who is interested in a more detailed description of the measurements is referred to the works in the ESRO series (in preparation).

2. MASS SPECTRA OF SPACE CHAMBER OILS

There are different investigations of diffusion pump oils [2], since the mass spectrum depends in many ways on the mass spectrometer used. As a consequence, all oil mass spectra in question are investigated in an oil-free Varian pump stand. These are the following:

(a) Heraeus backing pump oil

(b) Heraeus diffusion pump oil (high vacuum)

(c) Hydraulic oil (Mobile extra heavy)

(d) Diffusion pump oil DC 704

The residual gas spectrum of the pure, burned-out vacuum system is shown in Figure 2. Should there be masses above 44, their partial pressure is lower than approximately 10^{-14} Torr. With the Bayard-Alpert Ionization manometer, a pressure of $2.5 \cdot 10^{-11}$ Torr is then measured. Since this is already the x-ray limit of the measuring apparatus, the actual pressure is assumed to be lower, and with later measurements with a Helmer ionization manometer (electrostatic deviation) it was found to be $3 \cdot 10^{-12}$ Torr for the /2

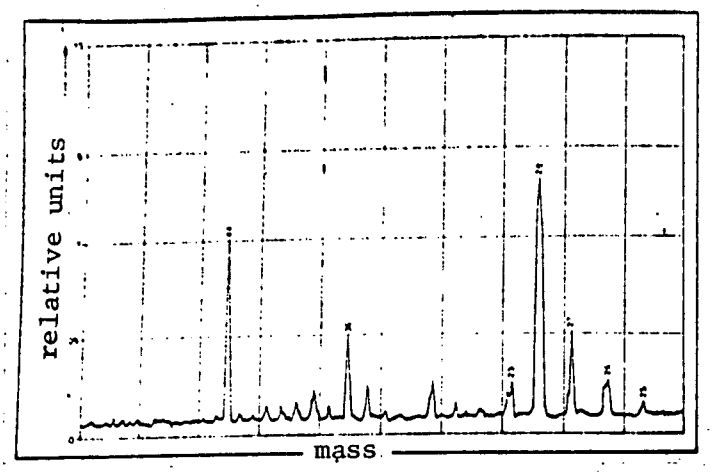

Figure 2. Residual mass spectrum of the pure burn-out UHV-pump stand, total pressure $2.5 \cdot 10^{-11}$ Torr.

same conditions.

After several experimental difficulties were eliminated (the entry system had to be modified several times), the mass spectra of these substances could be obtained. In Figures 3, 4, 5 and 6 the mass spectra are shown, while the masses below 50 are ignored and, in order to facilitate a better comparison, they are shown in relative units. The characteristic peaks of these oils are shown in Table 1. The peak height as well, as the vapor pressure corresponding to it (as obtained in the Barian system), is also included for the "most characteristic", which are named first. These masses are chosen in order to make the simplest possible differentiation. There are naturally different masses which show essentially higher peak heights, but they are mostly represented with other oils, so that they are not usable as a criterion. With the above peaks designated as "characteristic", the partial pressure behavior can be indicated in the first approximation. Still it must be mentioned that it is necessary to refer back to other masses, for example, by determining the fractions of backing pump hydraulic oil.

Figure 17 shows an original mass spectrum in order to demonstrate the performance capacity of the mass spectrometer (Heraeus Diffusion Pump Oil). The solution could have been somewhat higher, but the apparatus has proven its reliability; no disturbance occurred during all these investigations.

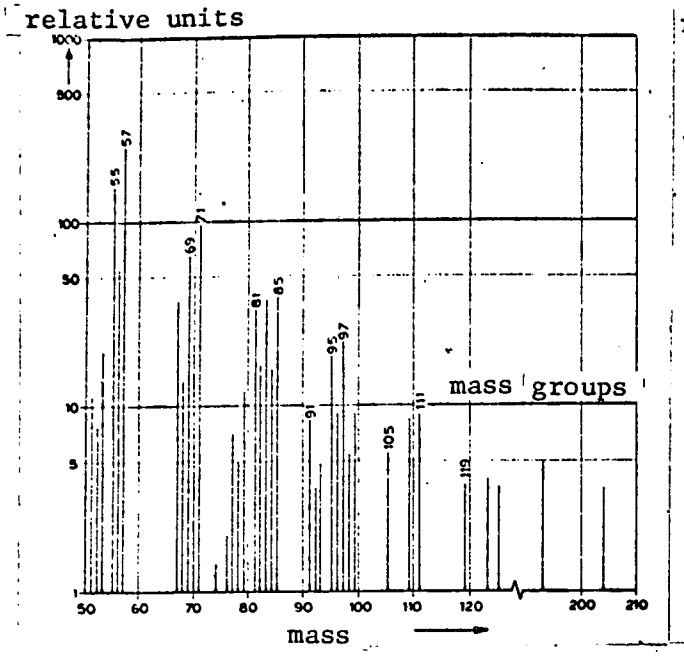

Figure 3. Mass spectrum of the Heraeus backing pump oil (recorded in the Varian system).

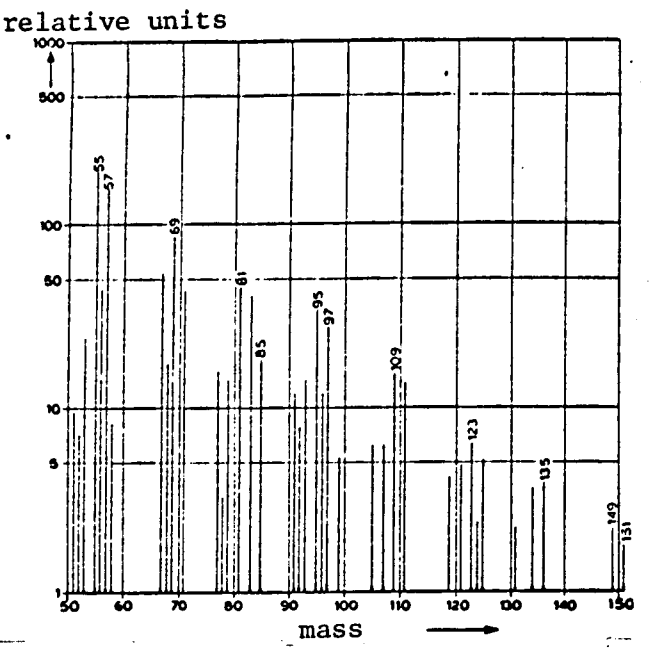

Figure 4. Mass spectrum of the Heraeus diffusion pump oil (recorded in the Varian system).

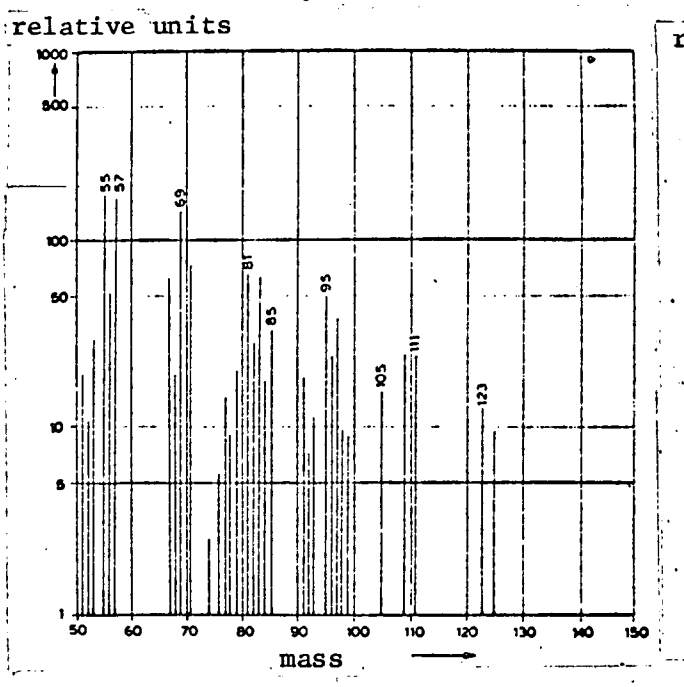

Figure 5. Mass spectrum of the hydraulic oil (recorded in the Varian system).

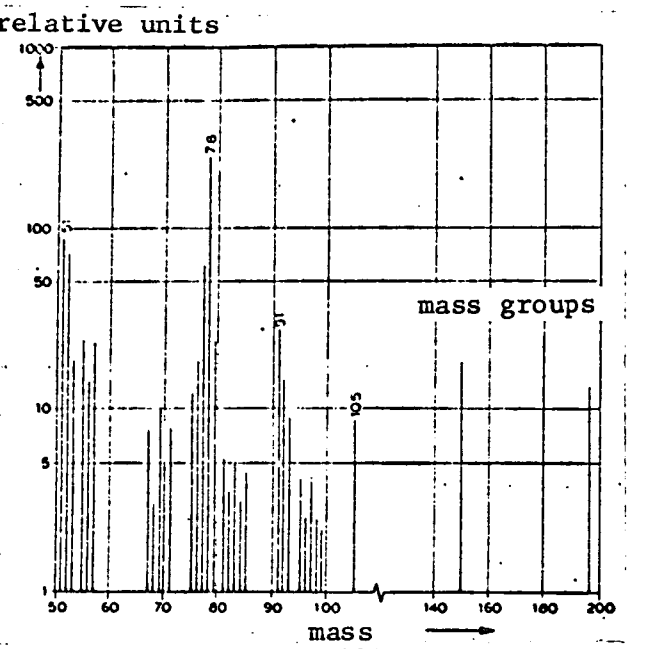

Figure 6. Mass spectrum of the diffusion pump oil DC 704 (recorded in the Varian system).

TABLE 1. THE MOST IMPORTANT PEAKS OF THE SPACE CHAMBER OILS.

		Torr
Heraeus diffusion pump oil	93, 91, 96, 111	$1.5 \cdot 10^{8}$
Diffusion pump oil DC 704	78, 51	$2.7 \cdot 10^{10}$
Backing pump oil	71, 83, 85	$1.2 \cdot 10^{9}$
Hydraulic oil	69, 81, 95	$1.2 \cdot 10^{9}$

The indicated partial pressure (Torr) is valid for the recording pen of one scale unit with the adjustment $100 \cdot 10^{-11}$ and a voltage at the secondary electron multiplier of 1700 volts. (These values hold with the mass spectra illustrated in Figures 10 and 15.)

3. TEST IN APRIL 1968 IN THE HBF 2 (FLIGHT MODEL I) /3

This was the first test in the space simulation chamber of Flight Model I. The satellite was radiated almost uninterruptedly by sun lamps, so that the time function of the partial pressures of the different masses could be investigated. The course of the partial pressures of the different masses to be discussed in the following section is shown relatively near the test beginning, in order to give an overall picture. (That is, the peak height of the masses involved measured at the beginning are made equal to one.)

The course of the dominating partial pressure in the residual gas is shown in Figure 7; hydrogen (2), water vapor (18), nitrogen (28), oxygen (32). The water vapor partial pressure drops after the cold wall is cooled by about two orders of magnitude; with nitrogen it drops about one order of magnitude (the same with oxygen). Also with hydrogen a decrease of approximately one order of magnitude is observed, even though — in contrast to the first substances — the final pressure is not obtained on the second test day. Even with the end of the test trial, a slight decrease was noticeable. In Figures 8 and 9, the peaks of the masses 69 (hydraulic oil) and 71 (backing

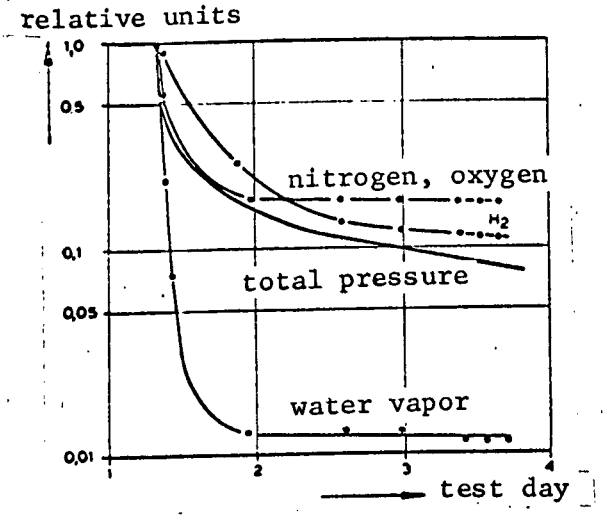

Figure 7. Temporal course of the peaks of hydrocarbons, water vapor, nitrogen and oxygen.

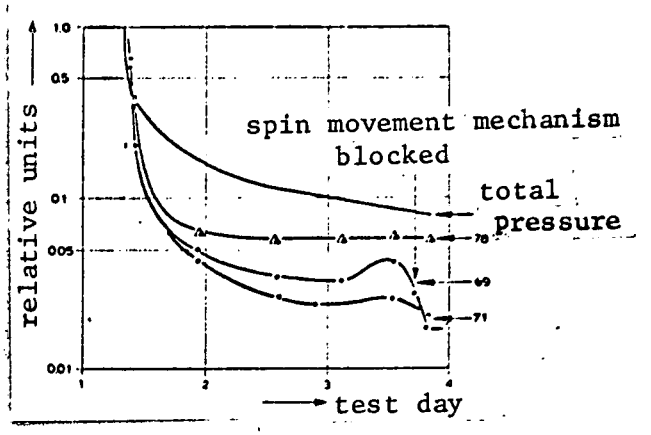

Figure 8. Temporal course of the peaks of mass 69 (hydraulic oil), 71 (backing pump oil), 78 (diffusion-pump oil DC 704).

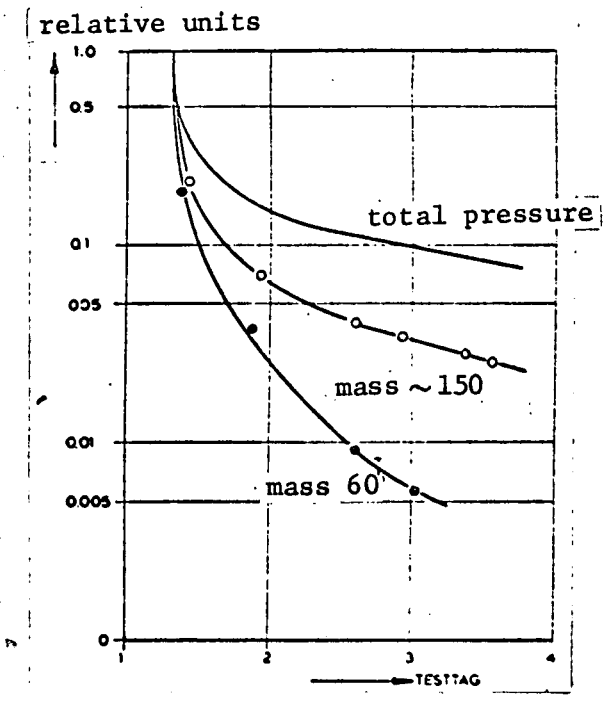

Figure 9. Temporal course of the peaks of mass 60 and ∿ 150.

pump oil) or those of the masses 60 and 150 are represented. While each of the peaks of the masses reached their end pressure after approximately one test day, those of masses 60 and 150 tended to drop toward the end of the test. Moreover, their partial pressure dropped to a relatively greater extent than the total pressure in the space chamber, in contrast to the first substances (Figures 7 and 8). This might indicate that the masses 60 and ∿ 150 are derived essentially from the satellite, and a reference to the mass spectra of the chamber oils also yields no noticeable peak heights on these masses.

Determination of the partial pressures in Torr units is very uncertain, since the differing ionization probability must be considered, as well as the absorption in the supply tube, among other factors. Such a listing of data might be included in Table II, because with these values a comparison with the hydrocarbons of the satellite as well as with the space chamber oils can be carried out. Furthermore, they should at least indicate the order of magnitude correctly. It is assumed that the peaks of the masses 69, 71, and 78 are only derived from hydraulic oil, backing pump oil, and diffusion pump oil DC 704. (Accordingly, the mass spectrum was recorded on the second test day at 14.47 h. See Figure 10.) /4

TABLE II. PROPORTIONS AND PARTIAL PRESSURES IN THE SPACE CHAMBER (APRIL TEST):

H_2	48%	$1.5 \cdot 10^{-7}$ Torr
H_2O	20%	$6 \cdot 10^{-8}$ Torr
Air ($N_2 + O_2$)	20%	$6 \cdot 10^{-8}$ Torr
Hydrocarbons		
All others about	8%	$2.4 \cdot 10^{-8}$ Torr

These compositions were determined on the second test day at 14.47 h. The total pressure amounts to $3.2 \cdot 10^{-7}$ Torr.

The peaks measured during the April tests of masses 69, 71, and 78 (second test day) represent a partial pressure for the following:

Hydraulic oil (69)	$1.8 \cdot 10^{-8}$ Torr
Backing pump oil (71)	$3 \cdot 10^{-10}$ Torr
Diffusion pump oil DC 704	$1.5 \cdot 10^{-10}$ Torr

recording pen (placement 100 10^{-11}, 1700 volt in sev)

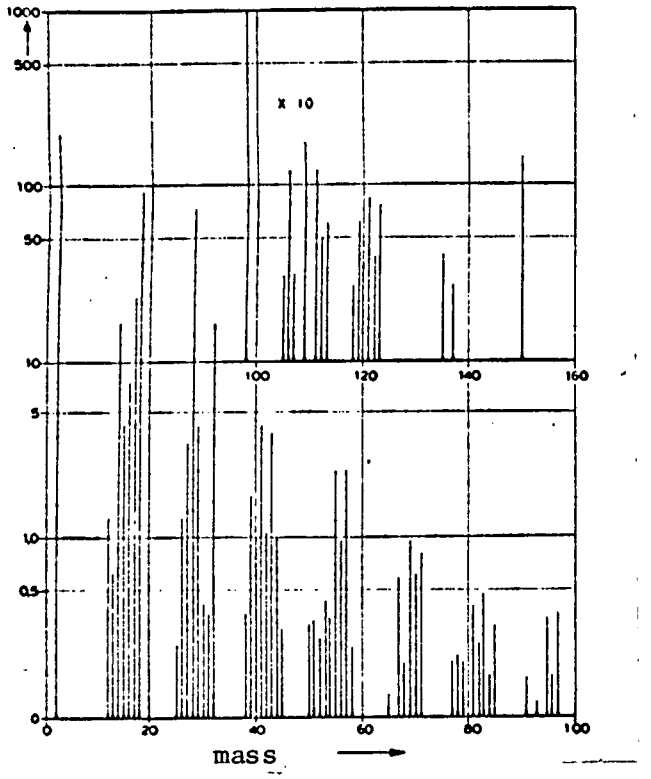

Figure 10. Mass spectrum of the residual gases on the second test day, recorded 14.47 h, April, test in the HBF 2

The partial pressure of the hydrocarbons amounts to about $2.4 \cdot 10^{-8}$ Torr (Table II), or with the above values it follows that about 70-80% of the hydrocarbons are derived from hydraulic oil.

On the third test day, the spin movement mechanism was blocked as the result of an oil leak in the hydraulic system. About two hours beforehand, an increase to mass 69 was observed (see Figure 8). After this increase, the partial pressure dropped to a lower value than before. This finding can be interpreted as follows: The relatively high proportion of hydraulic oil vapor allows one to conclude that the oil flow was not even completely satisfactory at the beginning of the test. The pressure rise is produced naturally from an enlargement of the leak rate, which then after about two hours determines the blocking of the spin movement mechanism (because the drops fell due to freezing on the cold gear teeth, as was subsequently determined). The partial pressure dropped again after the hydraulic motor became inoperative. The peak for mass 71 also shows a slight rise, and then a decline. Although this can be traced back to the components of the hydraulic oil, it means there is no rise in the backing pump partial pressure (see Figure 5).

To be sure, an essentially higher pressure prevails with hydraulic intervention than the mass spectrometer indicated. Still the measured partial pressure as regards the satellite — that is, the oil atmosphere, to which

the satellite was exposed — could be approximately right, for the hydraulic oil was to a great degree intercepted by the arm-cold wall complex surrounding the mechanism and was frozen out. Besides, the hydraulic oil molecules were forced to impinge on the cold wall at least once and be reflected from it before they could impact on the satellite. Since the cold wall represents a good cryogenic pump for the hydraulic oil, most of the oil has been removed from the test volume. The relatively lower pressure increase is thereby important. Whether the satellite toward the end of the test (with the warming of the cold wall) was still not exposed to a relatively strong oil atmosphere cannot be answered at this time. It should, nevertheless, be mentioned that, through corresponding precautions taken by the test personnel, the satellite can be retrieved unharmed from the space chamber.

Since the partial pressures of the residual gas components, which apparently are derived from the space chamber, remain constant for about 1-1/2 test days, the total pressure falls farther. It is assumed that this can be traced to the decreased gas yield of the satellite.

The total pressure on the second day amounted to $3.8 \cdot 10^{-7}$ Torr and dropped to about $2.5 \cdot 10^{-7}$ Torr toward the test end — that is, the gas yield Q' was reduced by:

$$\Delta \dot{Q} = \Delta P \cdot S = (3{,}8 - 2{,}5) \cdot 10^{-7} \cdot 2 \cdot 12000 = 3 \cdot 10^{-3} \text{ (Torr} \cdot \text{l/sec)} \qquad (1)$$

If it is assumed that the gas yield of the satellite is negligible at the end of the test, this value can then be regarded as the integral gas yield of the satellite on the second day. Since with an empty space chamber a final pressure of about $8 \cdot 10^{-8}$ Torr was reached (and, moreover, no pumping effectiveness of the cold wall was assumed), this value is too low. If this value is too low and circumstances are taken into account, one obtains for the integral gas yield of the satellite

$$\dot{Q} = 7 \cdot 10^{-3} \text{ Torr l/sec}$$

The pumping effectiveness of the cold wall is difficult to estimate, since this type of gas is not too well understood. It may not be considered as too important, since about 60% of the yield may be the gas hydrogen, which is not pumped from the cold wall. How high the gas yield of the satellite was at the beginning of the test is likewise difficult to estimate; toward the test end it may have amounted to about $4 \cdot 10^{-3}$ Torr l/sec. Further, it is noticed that Flight Model I had gone through several vacuum tests and thereby was well degassed.

4. TEST IN JUNE, 1968, IN THE HBF 2 (FLIGHT MODEL I)

The last test of Flight Model I took place in the same space chamber; it was naturally thoroughly purified beforehand of the hydraulic oil from the April test.

The test program permitted more attention to be directed to the dependence of these partial pressures on the movement simulation as well as the sun-shadow periods. The partial pressures of hydrogen, water vapor, oxygen, and nitrogen have the same behavior as in the preceding test and need not be discussed here. The peaks of the masses 60 and $\sim$ 150 are correspondingly lower, since the satellite in the preceding test could outgas, and toward the test end no unequivocal peak could be measured.

As is shown in the April test, the partial pressure from the DC 704 is too high at the beginning of the test. It may be assumed for that reason that a deposit of this oil could form on the satellite. In Figure 11 the partial pressure of the DC 704 is shown after switching on the sun simulators. According to our expectations, the partial pressure rises continually. After the shadow period, a higher peak has again been measured. It should be noted that here a slow rotation of the satellite is taking place (two rotations per hour). Furthermore, the radiation strength of one solar constant (hot orbit) is lowered to 0.25 solar constant (cold orbit, shadow period). The radiation times amount to 60 minutes or 40 minutes, respectively. The temperature on

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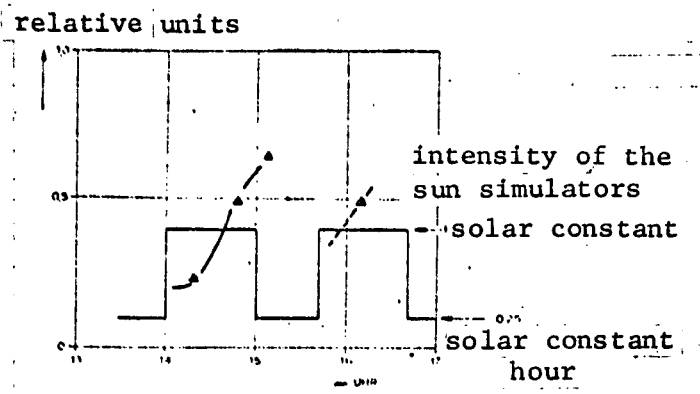

Figure 11. Temporal course of the peak 78 after switching on the Sun simulators (1. test day, April, 1968).

the satellite surface amounts to a maximum of about 60° C, or a minimum of -42° C on the shadow side. Since the oil partial pressure continuously rises into the shadow period, it is assumed that sufficient oil for the evaporation was still present on the satellite surface. As a consequence of the lower partial pressure of the DC 704 in the space chamber, it is assumed that this oil deposit disappears from the satellite in the course of time.

At the beginning of the second test day, difficulties occurred in the test installation. During this time, the sun simulators were functioning at a lower level of power. During this program, the satellite was not rotated, but only inclined about $\pm$ 35°. Unfortunately, the data processing unit did not work at the beginning of the test, so that no temperature measurements are available. It may be of importance that the temperature rose somewhat faster when the sun simulators were switched on than before (see Figure 11), whereby naturally a faster rate of evaporation of the diffusion pump oil was to be expected. The oil partial pressure for some sun-shadow periods is presented in Figure 12. The peak first rises sharply; with the following sun-shadow periods the partial pressure remains quite low. The explanation might be the following. As a consequence of the lesser radiation of the satellite, an oil film could have formed — if one assumes that the oil had completely vaporized beforehand. This oil film then evaporated during the orbit, so that no renewed rise could result in the following sun-shadow-period, because there was no longer oil film there. Shortly before the fourth orbit, about 15.10 h, a rise was determined. At the same time, the yoke was moved — that is, the position of the satellite in relation to

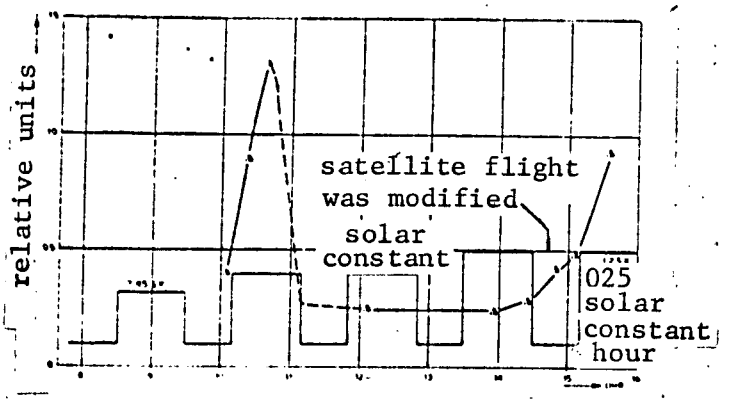

Figure 12. Temporal course of the peak 78 after switching on the sun simulators (2. Test day, June, 1968).

the sun was changed — while radiating naturally other parts of the satellite.

One can infer that the shadow period is not sufficient to form a deposit; as will be discussed later, this is also improbable.

During these investigations, the peak for the hydraulic oil (mass 69) does not show any noticeable changes. It remains constant after it reaches its end value (on the second test day); a slight variation could be traced back to the components of the DC 704. Only when the yoke was rotated so far, that the back side of the spin movement mechanism entered the beam of the sun simulators, did the partial pressure rise (see following section). In Figure 13, the satellite position had been changed to face the beam of the sun. The former position of the sun is given above. During the first two mass spectra, the same cover side of the satellite was radiated. With the third, the satellite was turned upside down, so that just the front side was radiated, and with the last three mass spectra the previously unradiated and therefore the cold back side was radiated. The peak of mass 78 accordingly fell at first, and later rose to almost double the value, as soon as the former back side hit the radiation beam. According to the interpretation of Figures 11 and 12, this was expected. The fact that the peak height was not as high as in Figure 12 was determined by the fact that the satellite was not perpendicular to the radiation, and thereby was not heated so suddenly. In the same diagram, the partial pressure of the hydraulic oil is given. A high peak was measured for mass 69 since in the first mass spectrum the yoke was rotated so extensively that the back side of the spin movement mechanism was already radiated. After the satellite was rotated from this extreme position and the spin movement mechanism was not any longer in the beam of the sun lamps,

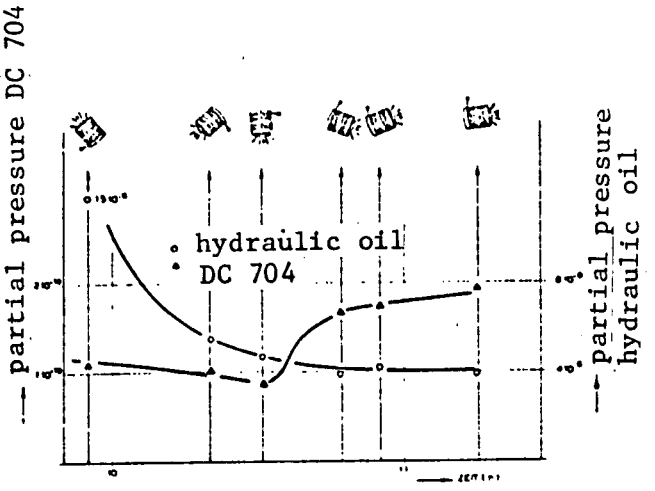

Figure 13. Dependence of the partial pressures of the hydraulic oil and of the diffusion pump oil on the satellite position.

the partial pressure of the hydraulic oil steadily declined and showed no influence at all whenever another side of the satellite was radiated.

One could ask why the hydraulic oil did not have the same dependence as the diffusion oil did.

According to the measurement with the Varian pump stand, the vapor pressure of the hydraulic oil amounts to 10^{-4} Torr. According to the Van der Hoff equation:

$$\ln p = -\frac{H}{R \cdot T} + \text{const.} \qquad (2)$$

at -50° C it is about $5 \cdot 10^{-8}$ Torr — the satellite surface was no colder — and is therefore higher than the partial pressure in the residual gas, that is, at this temperature it does not condense on the cold satellite back side. /6

The peaks measured during the June test of the masses 69, 71, and 78 represent a partial pressure for:

Hydraulic oil (69)	$4 \cdot 10^{-9}$ Torr
Backing pump oil (71)	$3 \cdot 10^{-10}$ Torr
Diffusion pump oil DC 704	$0.8\text{-}1.5 \cdot 10^{-10}$ Torr
Total hydrocarbons	$1.2 \cdot 10^{-8}$ Torr

The total pressure amounts here to $4.5 \cdot 10^{-7}$ Torr.

While the backing pump oil has the same value within this degree of measurement accuracy, the hydraulic oil partial pressure is about five times lower. At this time no apparent oil leak appeared in the hydraulic system. The final partial pressure of the DC 704 is about half as high as in the April test; even correspondingly higher values were measured after each satellite movement program. The hydraulic oil partial pressure is still high in comparison with the other oils. With these values, it follows that the share of the space chamber oils amounts to about 40% of the total hydrocarbons in the residual gas — that is to say, the satellite contributes at least as much to the impurities as the space simulation chamber.

We are now going to discuss the condensation of the diffusion pump oil on the satellite in more detail. (It is assumed for this observation that the molecular radius of the DC 704 amounts to 8 angstroms, and the molecular weight is about 500.)

With a given pressure it can be calculated that the gas pumped off in this interval amounts to:

$$Q = P \cdot S \cdot t \qquad (3)$$

in which:

P = pressure, partial pressure of DC 704

S = suction capacity of the pump

t = time.

The suction capacity cannot be assumed to be that of the two oil diffusion pumps, which amounts to 2·12,000 l/sec, because the cold wall represents a good cryogenic pump with an adhesion probability (α) of nearly one (to about 0.95 assumed), that is, almost all of the oil molecules impacting on the cold wall would condense out. According to kinetic gas theory, the suction capacity of the cryo-pump amounts to:

$$S = \alpha F \cdot \sqrt{\frac{R \cdot T}{2 \pi M}} \quad (4)$$
$$= \alpha \cdot F\,(cm^2) \cdot 2{,}7\ (l/sec \cdot cm^2)$$

where:

R = gas constant

M = molecular weight

α = adhesion probability

T = gas temperature, here that of the degassing satellite surface

F = surface of the cryo-pump.

The surface of the cold wall, which acts as a cryogenic pump, was estimated at about 20 m^2 (the efficiency of the diffusion pumps was disregarded in making the determination). With the above formula, the absorptive capacity of the cold wall is:

$$S = 5{,}4 \cdot 10^5\ l/sec.$$

From Figure 12 it can be concluded that after an hour of radiation the oil film is vaporized. (One can naturally raise the objection that the measured value in Figure 12 is not the maximum value or that the partial pressure of the DC 70 increased still further. Naturally, this value is not very exact, but still it is improbable that the peak would have risen so strongly, since the solar cell panels already reached the equilibrium temperature within 10 to 15 minutes. Nevertheless, this value is probably the highest, measured during the test, if the values at the beginning of the test are disregarded.)

In this period, a gas amount of approximately:

$$Q = \Delta P \cdot S_{total} \cdot t$$
$$= \underline{0{,}35\ Torr \cdot l}$$

is pumped off for which the substratum, that is, the end partial pressure of the DC 704, has been considered. Since a mole contains $6.02 \cdot 10^{23}$ molecules

in the normal state, it corresponds to:

$$\frac{760\ (\text{Torr})\ 22{,}4\ (\text{l})}{0{,}35\ (\text{Torr})\ 6{,}02\ 10^{23}} = 1{,}2 \cdot 10^{19}$$

The degassing satellite surface under consideration amounts to about 1 m^2 ($\pi/2$ x 80 cm x 80 cm Ø).

With a molecular radius of 8 angstroms, the densest spherical packing is about $2 \cdot 10^{18}$ molecules per monolayer on this satellite surface. With the above value, it follows that:

$$\frac{1{,}2 \cdot 10^{19}}{2 \cdot 10^{18}} = 6$$

That is, about six molecular layers on the average were previously present on the satellite surface. This value is reliable naturally only in the first approximation.

With a partial pressure of $1 \cdot 10^{-10}$ Torr, considerable time is naturally necessary, until a monomolecular layer can be deposited. The corresponding Formula (4), which is valid for condensation or evaporation equilibrium, shows that per cm^2 and second a gas quantity of:

$$\begin{aligned} Q &= 1 \cdot 10^{-10}\ (\text{Torr}) \cdot 1{,}56\ (\text{l/cm}^2 \cdot \text{sec}) \\ &= 1{,}56 \cdot 10^{-10}\ (\text{Torr} \cdot \text{l/sec}) \end{aligned}$$

is deposited, or about $0.55 \cdot 10^{-10}$ molecules of DC 704, as can be easily calculated. Since a monolayer contains $2 \cdot 10^{14}$ molecules per square centimeter, about 36,000 seconds are required until a monomolecular layer can be deposited. Or about 60 hours would be necessary for about six molecular layers. This amount of time is not available. From the data, it follows that the intensity of the sun simulators had dropped at 2°° h, or 8 h have elapsed up to the orbit where the mass spectrometer measurements were carried out (10.10 h). If one assumes that the deposit has been formed during this interval, then one must consider that a higher partial pressure of the diffusion pump must

have previously existed. That is, the number of oil molecules, which impinged on the satellite, must have been greater than can be determined from the mass spectrometer measurements. Here we should add: from the measurements in April, where no position and radiation changes were undertaken on the satellite, it follows that the partial pressure remained constant after about 1-1/2 days of experimental time. The oil, which during the start phase penetrates into the space chamber, would be pumped away from the cold wall until there was no discernible pressure if the subsequent flow of oil molecules were stopped. The suction parts of the oil diffusion pump are to be regarded as the main oil sources (see Figure 14). From the geometry of the chamber and the arrangement of the mass spectrometer pumps, it is concluded that the oil molecules diffusing into the space chamber could reach the mass spectrometer tube after reflection on the cold wall cover or on the satellite. Because most oil molecules freeze out on the cover wall, the number which can enter the mass spectrometer tube is correspondingly lower. In other words, the number of oil molecules coming from the suction parts and falling on the cold jacket of the cover and the satellite can undoubtedly be several times higher than one would conclude at first from the mass spectrometer tests. The oil partial pressure could therefore depend on the location and direction in the space chamber. It would be going too far astray to investigate this directional dependence with elaborate

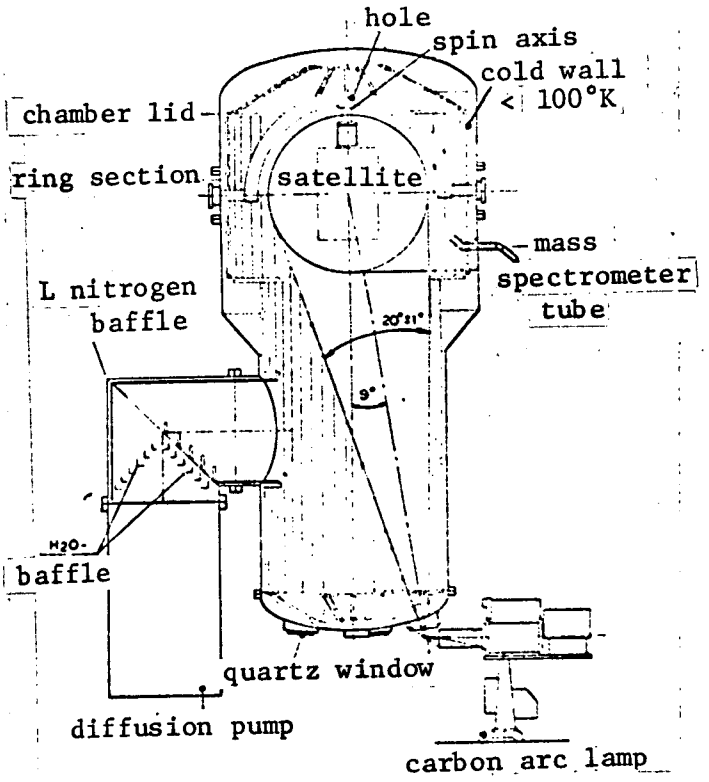

Figure 14. Schematic of the space simulation chamber HBF 2.

calculations [3], especially since the measured values are not very exact.

5. TEST IN MAY, 1969, IN HBF 3 (FLIGHT MODEL II)

Flight Model II was tested in the space simulation chamber HBF 3; during this test the sun simulators were running almost continuously. The production procedure of the satellite was modified at times, but for lack of time, spectrometric tests had to be omitted. The investigations correspond to the April test in the HBF 2 and permit a comparison of the two space simulation chambers. The temporal course of the partial pressures of water vapor, nitrogen, and oxygen corresponds to that in HBF 3 and should not be treated further here. The same pertains to the peaks at the masses 60 and $\sim$ 150 which could not originate in the chamber.

A few statements about the chamber should be made. The final vacuum was here $3.4 \cdot 10^{-6}$ Torr. It is completely adequate for the thermal investigations, but is still an order of magnitude worse than in the HBF 2. The main reason is probably the integral leak rate of the chamber. As was determined in the mass spectra, there are very high portions of nitrogen and oxygen (together about 60%) in the residual gas, and almost in proportion to the atmospheric percentages. The partial pressure of the nitrogen exceeds that of the water vapor.

With the suction capacity of the three oil diffusion pumps ($3 \cdot 12{,}000$ l/s) and the partial pressure of air ($2 \cdot 10^{-6}$ Torr), one obtains the integral leak rate of the space chamber as follows:

$$\begin{aligned} Q_{leak} &= S \cdot P \\ &= 3 \cdot 12{,}000 \ (l/\text{sec}) \ 2 \cdot 10^{-6} \ (\text{Torr}) \\ &= 7 \cdot 10^{-2} \ \text{Torr } l/\text{sec} \end{aligned}$$

This rate of leakage is relatively high.

Most recently, CO_2 was frequently mentioned, which as a precipant on the cold wall could change its optical characteristics. With this high leakage rate for air, a certain amount of CO_2 could penetrate into the space chamber. A short calculation produces the result that this is decidedly lower than could be concluded from the peak of mass 44 (CO_2) on the assumption that it only consists of CO_2. According to measurements of [4], there is a great change in the optical properties if layer thicknesses of 10 to 100 microns are attained.

With the partial pressure of CO_2, one could obtain in about 10 days test time only fractions of the above quoted layer thicknesses. It should be added that the CO_2 has such a high vapor pressure that considerable evaporation could occur if one did not presuppose additional pumping efficiency at the existing temperature of the cold wall of about 90° to 100° K through the trapping effect [5]. A modification of the optical properties of the cold wall through CO_2 deposit precipitation is not to be expected for the usual test periods. The cold wall absorbs a considerable part of the CO_2, as can be seen from the strong rise of peak 44 (even with a slight rise of the cold wall temperature). Due to the large surface of the cold wall, the total amount of absorbed gas is large, even if only a few molecule layers are absorbed.

Since the HBF 3 was not operated with silicon oil DC 704, but with the Heraeus high vacuum, the peak was not pronounced for the mass 78. The differentiation of the diffusion pump oil from the backing pump oil and hydraulic oil is correspondingly more difficult. Figure 15 shows a mass spectrum (recorded on May 2, 1969).

The measured peaks of the masses 69, 71, 93 during the May test in HBF 3 correspond to the following partial pressures for

Hydraulic oil (69)	$1.4 \cdot 10^{-8}$ Torr
Advance pump oil (71)	$2.5 \cdot 10^{-9}$ Torr
Heraeus diffusion pump oil (93)	$7 \cdot 10^{-9}$ Torr

recording pen (position 100 10^{-11}, 1700 volts at sev)

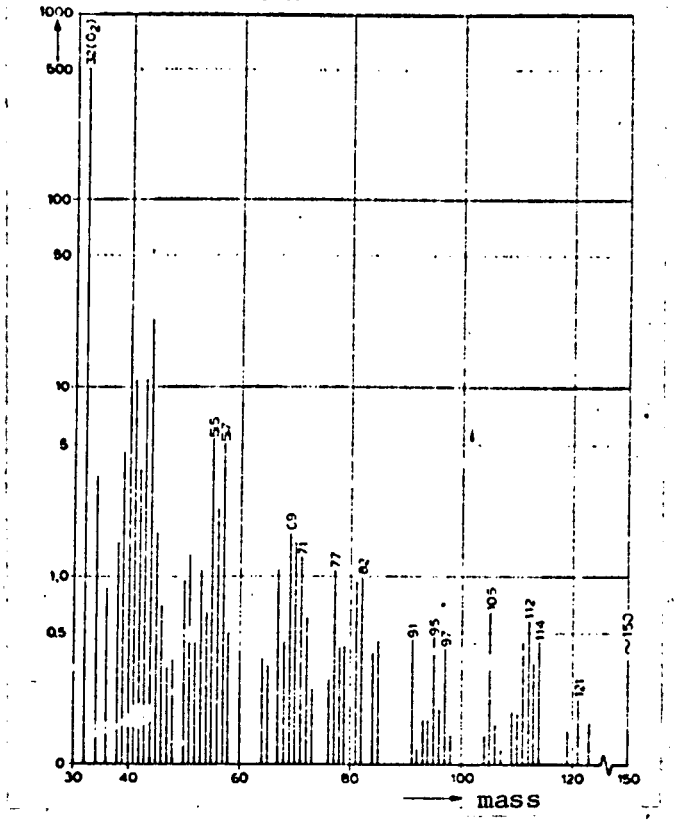

Figure 15. Mass spectrum of residual gas in the HBF 3 (recorded during heat balance test of Flight Model II, May 1969)

The total pressure amounted to $3.4 \cdot 10^{-6}$ Torr; the partial pressure of the hydrocarbons altogether is estimated at $8 \cdot 10^{-5}$ Torr.

These partial pressures of the space chamber oils are valid under the assumption that the peaks originate only from these oils. Since the substances, which have peaks in the mass region 105 to 114 (as well as $\sim$ 150), (and those which do not come from the chamber oils) surely have mass components 69, 71, and 93, the indicated partial pressures may be too high.

One obtains about 2.5% for the /8 total hydrocarbon fraction in the residual gas, which corresponds to a partial pressure of about $8 \cdot 10^{-8}$ Torr. The partial pressure of the space chamber oils amounts to $2.4 \cdot 10^{-8}$ Torr, or their share in the total hydrocarbons amounts to 30% in the residual gas. These values are significantly higher than in the HBF 2, and even the portion of hydrocarbons which apparently come from the satellite, as well as that which comes from the space chamber. Here it is worth noting that with Flight Model II fewer vacuum tests can be carried out, so that a higher degassing rate is to be expected than with Flight Model I. Moreover, the diffusion pumps are directly applied to the chamber (test volume), so that the molecules of the diffusion pump oil are able to reach the experimental volume, in contrast to the HBF 2, where several reflections are necessary. Since the backing vacuum pump oil

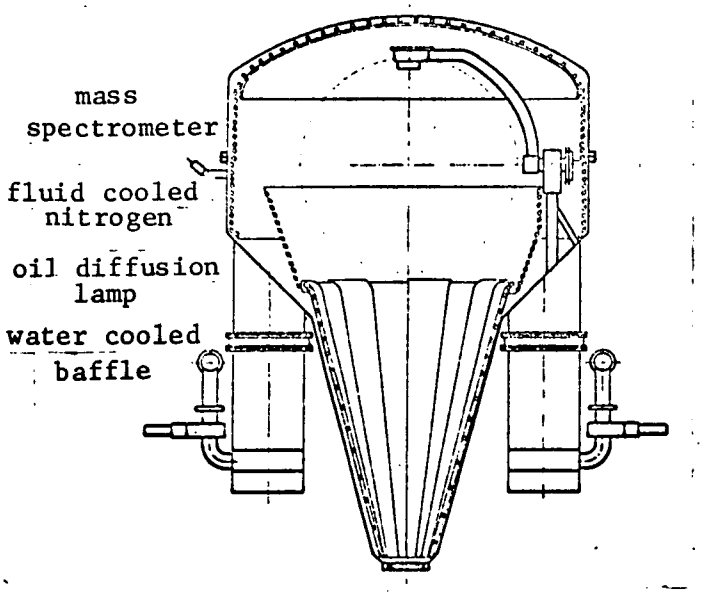

Figure 16. Schematic of the space simulation chamber HBF 3.

frequently passes through diffusion pumps into the vacuum chamber, the higher share of backing pump oil ought to be clarified (Figure 16).

The peak 69 for the hydraulic oil lets us conclude that leakages in the hydraulic system were present, even though no interruption of the test was necessary. The partial pressure of the hydraulic oil is also higher than that of the diffusion pump and backing pump oil.

6. CONCLUDING OBSERVATIONS

From these investigations, it can be concluded that:

(1) At the beginning of the test the partial pressure of the space chamber oils is relatively high. It is high enough to form a deposit on the satellite of several molecular layers. However, this oil film is removed in the course of the test.

(2) The partial pressure of the oil film was highest in both space chambers. On account of the high vapor pressure, no hydraulic oil film appears to form on the satellite.

(3) If we disregard the beginning and end phases, the satellite contributes more to the impurities in the residual gas (hydrocarbons) in such tests than does the space chamber.

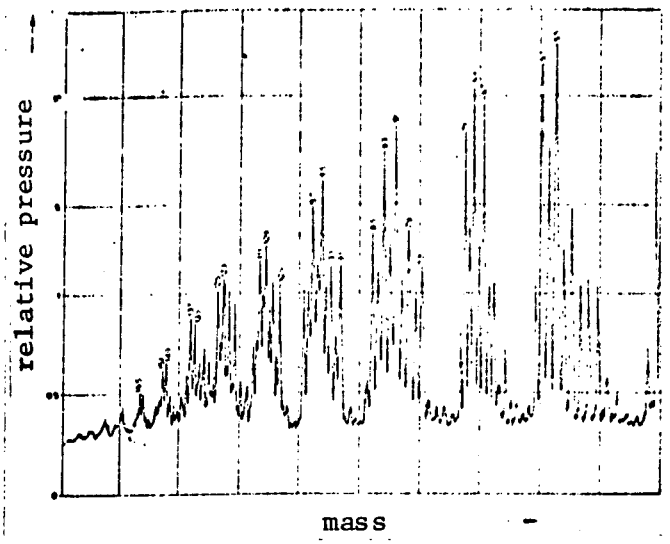

Figure 17. Mass spectrum of the Heraeus diffusion pump oil total pressure $3.7 \cdot 10^{-3}$ Torr, original mass spectrum. The ordinate is divided into three linear regions of 0-1, 1-10, 10-50.

The HBF 3 is being refitted for the forthcoming TD satellite test (prototype) for ion getter and sublimation pumps. This is naturally the cleanest solution in vacuum technology. It is to be hoped that the gas yield of the satellite is correspondingly low, and the space chamber is not contaminated by the satellite.

We believe we can state that mass spectrometer supervision of residual gas with thermal satellite tests is to be recommended, inasmuch as the test team could occasionally eliminate various faults. These measurements, as far as practicable, ought to be perfected, so that during the test reference can be made to various defects (for example, leaks in the hydraulic system or in the helium tanks).

It should be emphasized that the existing measurements are not very exact. They ought only to be regarded as comparison values. The data for the absolute partial pressures entail a high degree of error for experimental reasons.

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